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Using remote sensing data for integrating different renewable energy sources at coastal site in South Italy

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Abstract

Italian coastal sites have the advantage of favorable climatic conditions to use mixed renewable energy sources, such as solar and wind. Harbors are safe places to install wind turbines where wind conditions are almost offshore. Space-borne remote sensing can provide information to determine solar and wind energy production potential cheaper than usual observational activity to identify and assess suitable areas. Here, we present a case study for both energy resources assessment from satellite in harbors.

Peer-review under responsibility of the organizing committee of the General Assembly of the European Geosciences Union (EGU)

Keywords: Remote sensing; SAR; Wind; Solar radiation; Renewable Energies

1. Introduction

To date, the policies of reducing Greenhouse Gas emissions, energy saving and a secure and efficient supply of renewable sources, are supporting the creation of “Green Ports”: i.e. sustainable port facilities with zero emissions. The Permanent International Association of Navigation Congresses (PIANC) founded in 1895 in Brussels, including port authorities around the world, has in this regard established the Working Group "Renewable Energy for Maritime Ports" [1].

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The main objective of this work is to establish a pilot within the Italian Calabria Region (Fig. 1), using the port of Vibo Valentia at the Tyrrhenian coast (Fig. 1), as a test case, within the Italian "Green Port" project. The goal of the project was to define a model for the integrated management of energy from renewable sources and energy efficiency, to reduce the impact of the port area on the environment. The main activity concerned to establish and evaluate a methodology to estimate the environmental parameters functional to assess wind and solar energy potential i.e. wind speed and solar radiation.

In this study, we used space-borne remote sensing for retrieving time series of wind speed and direction and solar radiation [2, 3, 4].

For wind, satellite observations of the ocean surface from Synthetic Aperture Radars (SAR) [5, 6] provide information on the spatial wind variability over large areas at higher spatial resolutions but at lower time resolution than scatterometers i.e. QuikScat [2, 7].

Several studies from the North Sea have shown that SAR images are a reliable source of information for estimating offshore wind climatology [2, 6]. Studies relating to the North Sea show biases compared to on-site data from weather stations as less than 5% for the average wind speed and below 7% for the parameters A (m/s) and k of the Weibull distribution, when a sufficient number of samples is available [4, 5].

This is of special interest in the Mediterranean [2, 8, 9], where spatial wind information is only provided by sparse buoys, often with long periods of missing data. In a previous study [9], a good agreement was found between the climatology from SAR and from a time series collected at the town of Crotone at the Ionian east coast of Calabria. Therefore, a possible option is to use offshore measurements to predict the climatology at a coastal site.

For solar radiation, the Down-welling Surface Short-wave-Flux radiation (DSSF) is a product available from Meteosat Second Generation Spinning Enhanced Visible and Infrared (MSG-SEVIRI). The estimated DSSF product derived from the Land Surface Analysis Satellite Application Facility (LSA-SAF) covers Europe [10] and it has been validated with in situ data stations [11, 12]. In a previous paper [13], the results showed a difference of about 55W/m^2 and 87W/m^2, for clear and cloudy sky conditions between instantaneous satellite estimates and ground measurements, respectively.

In this study, we present a comparison between the measured power production of a photovoltaic, PV, plant and the estimated power production using DSSF as input to the power curve of the PV plant. Furthermore, we use SAR data to predict the wind climatology at the harbor of Vibo Valentia. Since in-situ measurements were not available, we considered data from a site located 30 km away. Since the Calabria Region is a long and narrow mountainous peninsula with significant wind variability from one coast to the other, we discuss the influence of the orography on the offshore wind spatial variability.

2. Datasets and methodology

2.1. Wind speed, ENVISAT

SAR images from March 2002 to April 2012 from the ENVISAT mission of the European Space Agency (ESA) Wide-Swath-Mode (WSM) were acquired over the Mediterranean area around Italy. The ASAR is a C-band VV and HH instrument with a 405 km swath with 150 m and 1 km resolution in wide-swath mode. Wind speed was retrieved using the Johns Hopkins University, Applied Physics Laboratory (JHU/APL) software APL/NOAA SAR Wind Retrieval System (ANSWRS version 2.0) [7].

The software uses an algorithm that employs the CMOD-5n algorithm [14]. The algorithm creates a wind field image by passing information about polarization, ascending/descending pass, incidence angle and wind direction from the wind model data, to the CMOD-5n algorithm, and applies a land mask. The algorithm is initialized using wind directions determined by the Navy Operational Global Atmospheric Prediction System (NOGAPS) models interpolated in time and space to match the satellite data. NOGAPS data are available at 6-hour intervals mapped to a 1° lat./long. Grid and the wind vectors at around 10 m height.

Here, we used SAR to produce maps of average wind speed U (ms^{-1}), Weibull parameters A (ms^{-1}) and k and wind power density E (Wm^{-2}), to 10 m asl with a resolution of 0.02 ° grid lat/long and over the South Italy domain in Fig. 1 below.

Fig. 1. The Calabrian Region and the sites of Vibo Valentia and Lamezia Terme

2.2. Solar radiation. MSG SEVIRI

We retrieved the DSSF from the MSG-SEVIRI instrument developed by LSA-SAF, over the Calabria Region for a period from October 2013 to June 2014. A standard day consists of 48 files in HDF5 format, one image every 30min. Analyses were carried out in the original projection and spatial resolution of the DSSF products in order to reduce the impact of data re-sampling caused by re-projection, and data were extracted at Ricadi site close to Vibo Valentia area.

Additionally, for a quantitative analysis, measurements are co-located in time taking into account a specific linear function of the longitude. The LSA-SAF algorithm [10] estimates the DSSF from the three short-wave SEVIRI channels (centered at 0.6, 0.8, 1.6 µm) at a spatial resolution of 3km.

Different parametrization procedures for clear and cloudy sky conditions were developed for this algorithm because DSSF is strongly depended on solar elevation and cloud coverage.

2.3. Coastal surface wind observations.

Due to the lack of time series of wind speed and direction at the site of Vibo Valentia, we use hourly data of wind speed and direction from a 10 m mast located 30 km away in the CNR-ISAC experimental site of Lamezia Terme, 600 m inland (Fig. 1) during a two-year period 2007-2008.

Vibo Valentia and Lamezia Terme are located in the Central part of Calabria in the Santa Eufemia Gulf. Lamezia Terme is located in the northern part and Vibo Valentia at the southern end.

2.4. Power production from a photovoltaic power plant.

We used hourly measurements of the actual power output data (DC power), in-plane solar irradiance, and solar cell temperature from a photovoltaic system located at Ricadi (38,63 LAT, 15,85 LON), close to Vibo Valentia with Nominal Peak Power of 19,85 kWp.

The photovoltaic panel is a SHARP model with 97% efficiency.

2.5. Results

2.5.1. Solar resource assessment

Fig. 2*a* shows the scatter plot of the power production measured at the PV plant located at Ricadi, and the power production computed using DSSF. From the comparison between observed and retrieved power production, we estimated the bias (mean value of the errors) and RMSE (Root Mean Square Error).

There is a slight overestimation of the power production of the PV plant with a bias of 2,2 Wh/KWp and the RMSE of 5,4 Wh/KWp (Table 1).

All Sky	(Wh/kWp)
Bias	2.2
RMSE	5.4

Table 1. Hourly radiation bias and RMSE for the period October 2013 - June 2014.

After evaluating the solar radiation retrieval methodology, we estimated the power production over the area in Fig. 2b using DSSF and a theoretical panel with 1 kWp and efficiency of 84%, with a theoretical PV power curve "SOLAR" used in the MATLAB community, with time resolution of power output of 10min.

Fig. 2*b* shows the map of mean power production (KWh/kWp) during June 2014, at 12 UTC.

a)

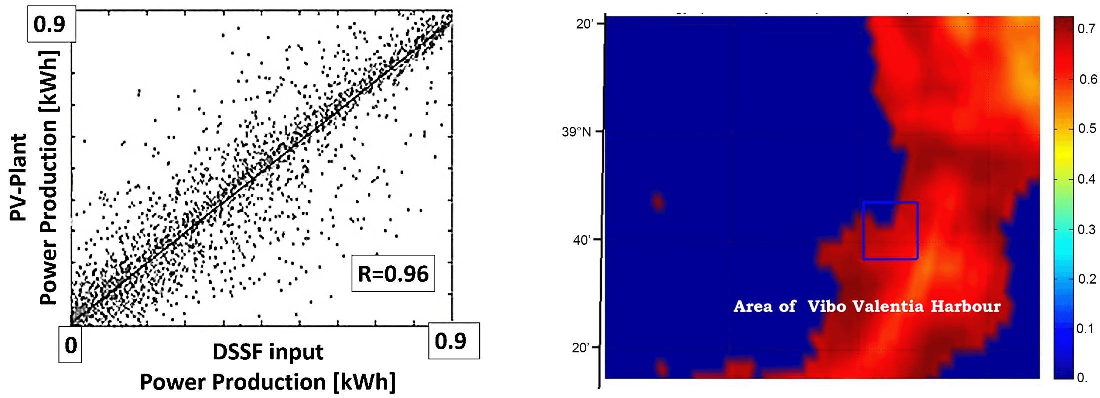


Fig. 2. (a) Scatter plot DSSF as a function of the PV plant output (Ricadi site) co-located in time, in all sky conditions and computed for whole period; (b) map of mean power production (kWh/Kwp) in the Calabria region during June 2014 at 12 UTC, using a theoretical panel of the 1kWp (Vibo Valentia harbor area).

2.5.2. Wind resource assessment

The maps of mean wind speed and energy density from SAR are produced using the Satellite–Wind Atlas Analysis and Application Program (S-WAsP) tool developed by the Technical University of Denmark (DTU) for wind resource assessment.

An example of how high resolution SAR images allow seeing wind field patterns induced by the orography is shown in Fig. 3, where the energy density is shown for the area offshore the central Calabria Region.

Fig. 3 shows the high offshore energy density at the northern part of the Santa Eufemia gulf with respect to the southern area.

This is associated to the Marcellinara gap i.e. the only valley that connects the Tyrrhenian Sea to the Ionian Sea, west-east oriented, which channels both the sea breeze and the synoptic flow systems.

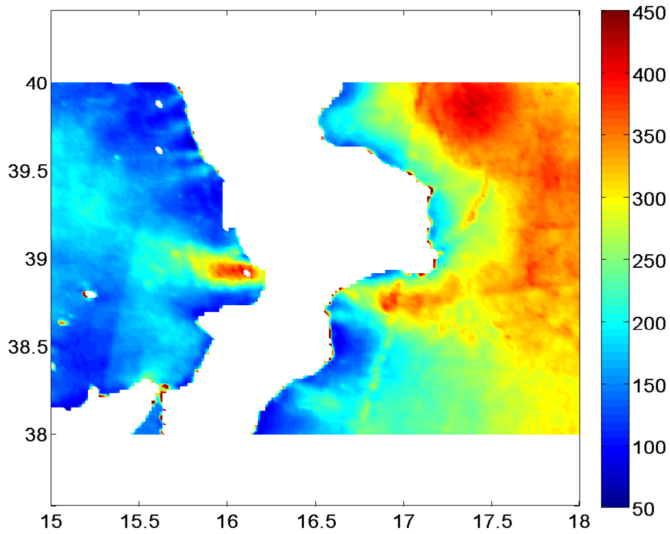


Fig. 3. Wind power density E (Wm-2) from SAR, offshore the central area of the Calabria region. Period: 2002-2012. We note that offshore the northern end of the Santa Eufemia Gulf the wind speed is higher that offshore at the southern end in front of Vibo Valentia due to the channelling effect of the East-west oriented valley of the Marcellinara Gap.

Statistical analysis for the nearest point offshore the harbor of Vibo Valentia and for the inland met mast of Lamezia Terme is given in Fig. 4 as wind roses and frequency distributions, and in Table 2 in terms of U, and Weibull A and k parameters.

Parameters	Mast	SAR
U (m s^{-1})	3.2	5.6
A (m s^{-1})	3.4	6.3
K	1.13	1.70

Table 2. Comparison of the mean wind speed *U* and Weibull coefficients A and *k* from the meteorological mast at Lamezia Terme (2007-2008) and SAR (2002-2012).

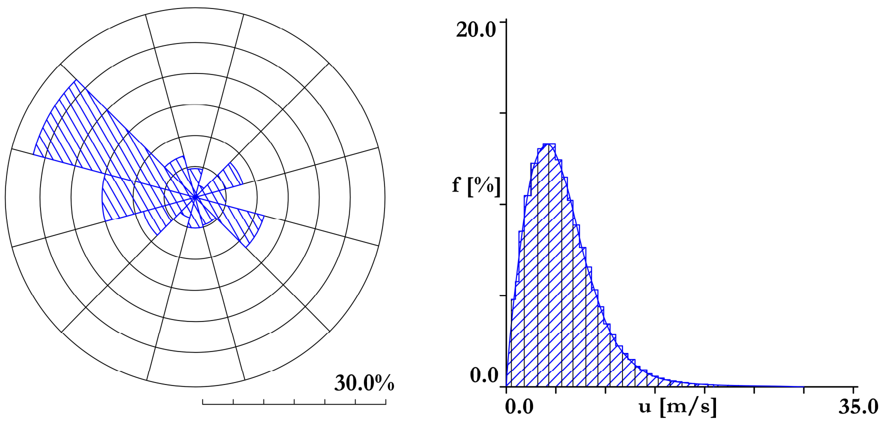
Fig. 4 shows the comparison of the wind climatology from SAR, offshore Vibo Valentia and from the experimental site of Lamezia Terme, 600 m inland (see also Fig. 1) where a time series was available during the period 2007-2008 at a 10 m meteorological mast.

We note a difference in wind roses likely because the site of Lamezia Terme is impacted by the flow channelling of the Marcellinara gap, while Vibo is in a position sheltered by the coastal mountain chain. Furthermore, we note a lower mean wind speed in Lamezia Terme with respect to offshore Vibo Valentia.

This is likely due to two factors: i) Lamezia is located in a flat area with strong night time stability with low winds; ii) SAR wind speed is overestimating for U< 2 ms-1. On the other end, from Fig 3, we see that at the northern end of the Santa Eufemia Gulf, wind speed is higher than at the southern end in front of Vibo Valentia due to the Channeling effect of the Marcellinara gap valley.

This case shows that there should be caution in deriving coastal climatology from other sites along the coast or from offshore measurements far away from the coastal site since local effects induced by the orography might have an important impact on the flow feature offshore.

a)



b)

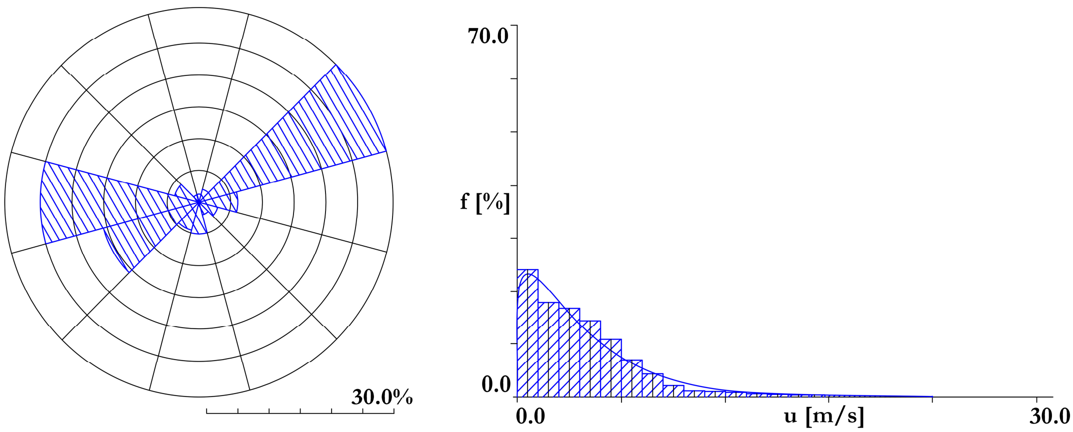


Fig. 4. (a) Wind roses (left) and frequency distributions (right) of wind speed and directions Offshore Vibo Valentia; (b) wind roses (left) and frequency distributions (right) of wind speed and directions at the inland site of Lamezia Terme.

3. Conclusions

The objective of the presented study mainly concerned to evaluate the use of space-borne remote sensing to retrieve wind speed and radiation to assess energy potential of renewable sources in the harbour area of Vibo Valentia. Given the lack of in-situ measurements, we used SAR images from the ENVISAT mission of the European Space Agency ESA for wind retrieval and the DSSF products from MSG-SEVIRI for retrieval of solar radiation. For solar radiation, the DSSF product gave reliable estimate of power production of a PV system where measured power data were available. For wind speed, we found that the local orography features can impact on wind on the offshore wind spatial variability. Therefore, one should carefully choose the location offshore where to retrieve wind time series. Furthermore, low winds during inland night-time stable conditions are not represented offshore.

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